Effects of biomass smoke from southern Africa on stratocumulus over southeast Atlantic Ocean

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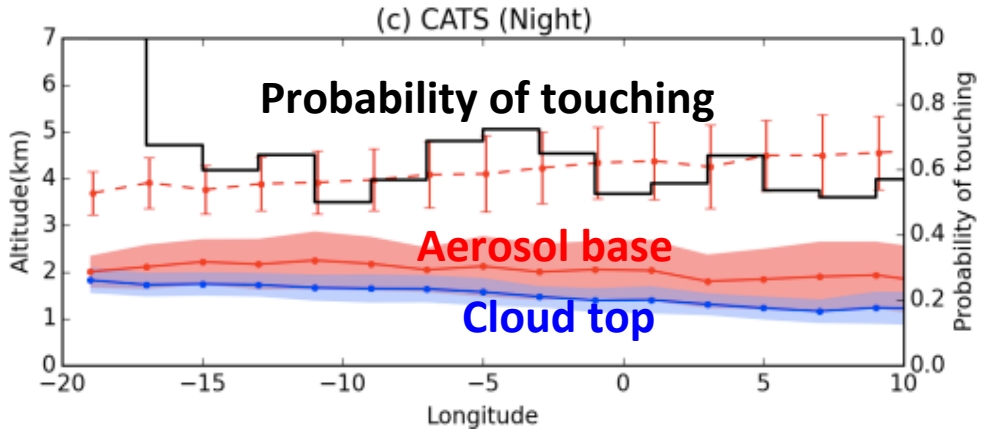
Motivation

- Many previous studies
  - suggested that BB aerosol plumes well separated from underlying SC clouds [1,2]
  - focused on direct and semi-direct effects of BB aerosols in this region [3,4]
- New evidences from NASA CATS satellite (and in-situ measurement) [5]
  - higher probability of mixing between aerosol and cloud
  - suggesting potentially important aerosol microphysical effect

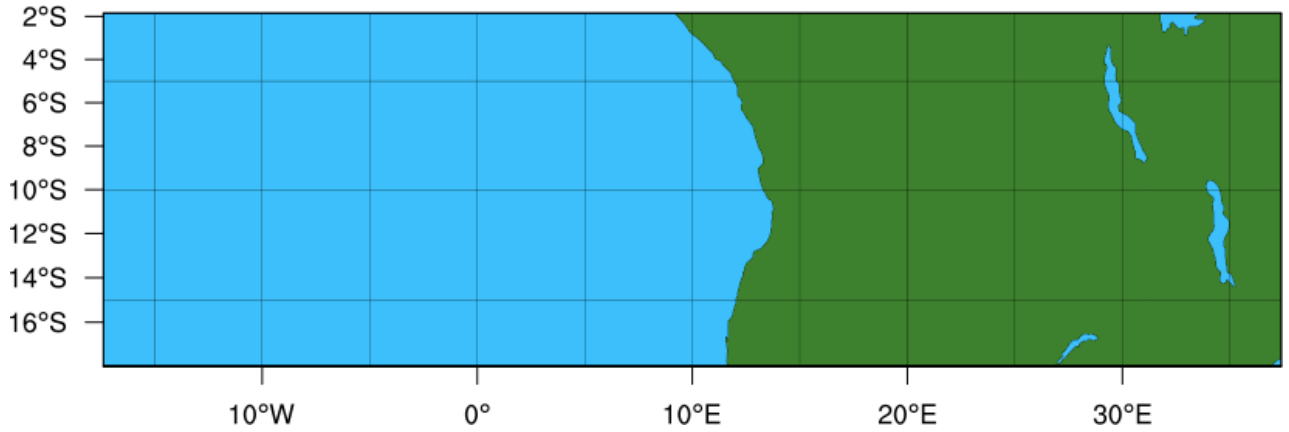


Modified from Rajapakshe, Zhang et al. 2017

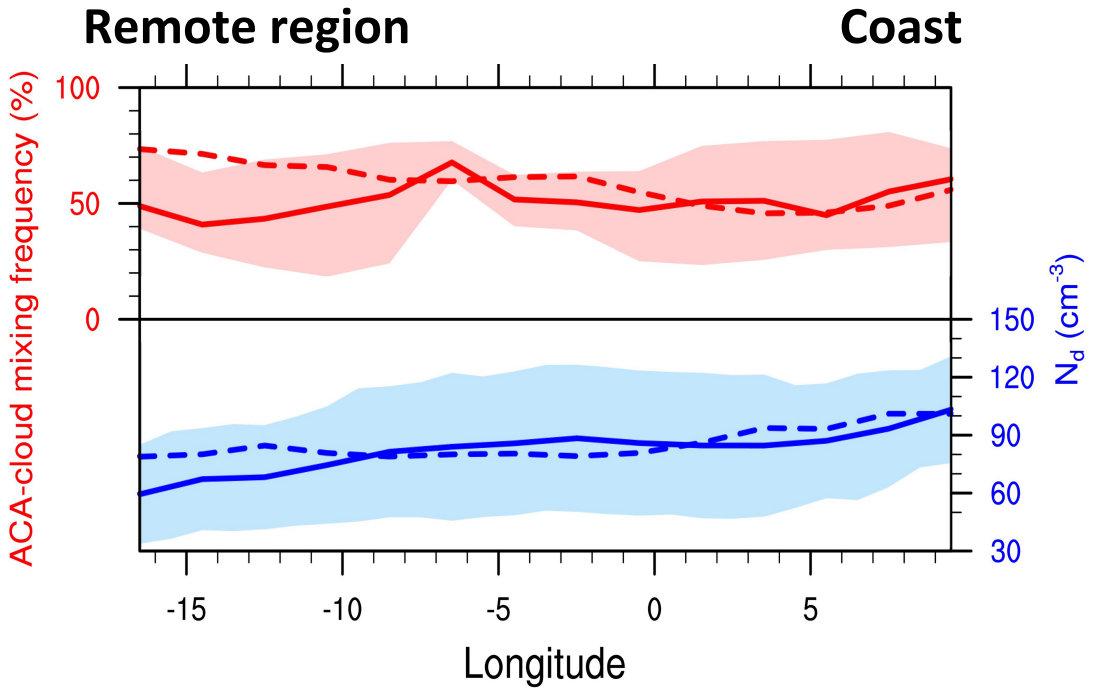
1. Hobbs, 2002; 2. Wilcox, 2012 ; 3. Chand et al., 2009; 4. Sakaeda et al., 2011; 5. Rajapakshe et al., 2017

Model and Data

- WRF-Chem model V3.6.1
- Domain and spatial resolution: 6000 km (Δx=3 km, E-W) × 1800 km (Δy=3 km, S-N) × 42 (v)
- Period: August 1 – September 30, 2014
- Three cases: **P-case**, **C-case** (only sea salt and DMS-generated aerosols), and **M-case** (radiative effect of smoke not considered)
- Aerosol-cloud-radiation interactions in WRF-Chem
  - MOSAIC aerosol scheme; Abdul-Razzak and Ghan cloud droplet activation parameterization
  - Cloud microphysics: Morrison two-moment scheme
  - Radiation: Goddard SW + RRTM LW schemes

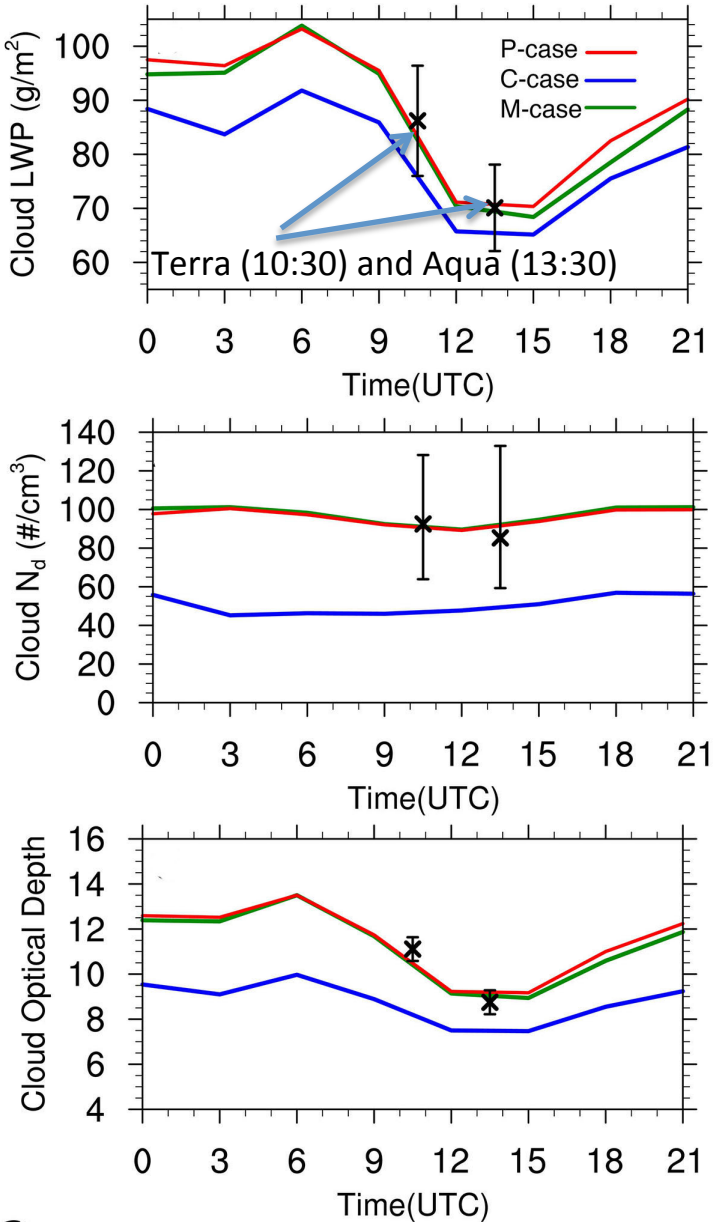


Evaluation – BB aerosols as CCN



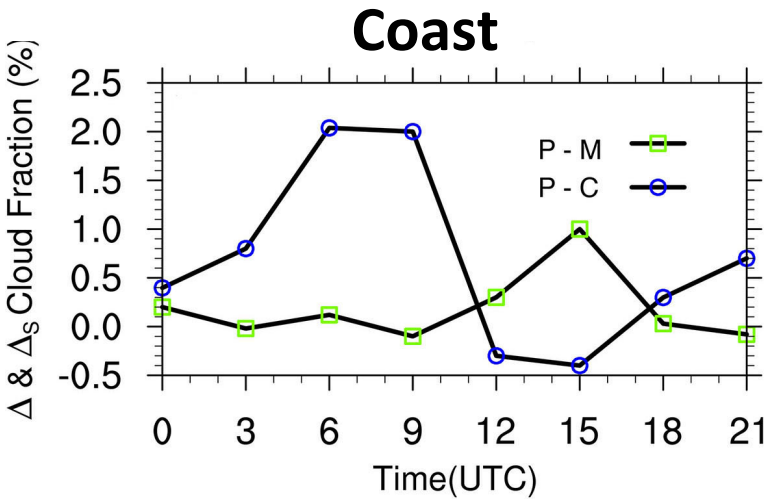
- **ACA (above-cloud aerosols) – cloud mixing frequency**
  - Retrieved from CATS observations (aerosol features adjacent to cloud layer).
  - Model overestimates mixing frequency over the remote region by about 15%
- **Cloud droplet number concentration (N_d)**
  - Retrieved from MODIS observations of liquid water path and effective radius.
  - Model overestimates N_d over remote region

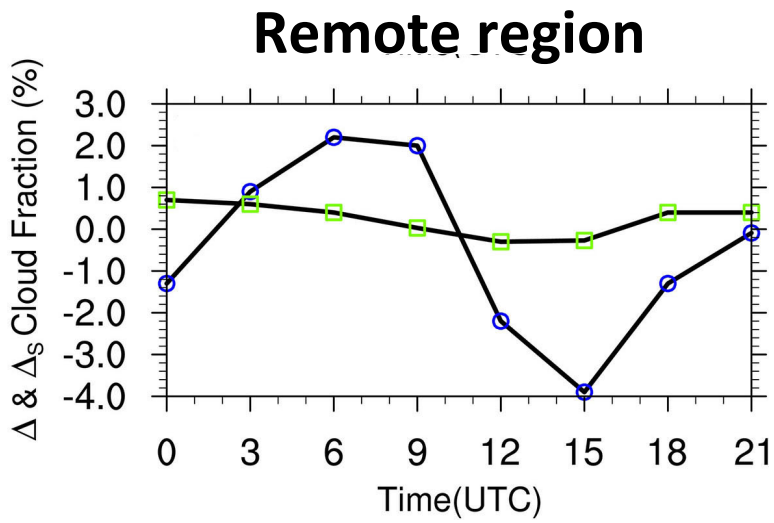
BB aerosol effects on stratocumulus



- **Liquid water path (LWP)**
  - Strong diurnal cycle; highest at 6 UTC and lowest at 15 UTC
  - P-case predicts higher LWP compared to C-case
- **N_d**
  - No strong diurnal cycle
  - P-case predicts about twice N_d of C-case
- **Cloud optical depth (COD)**
  - Diurnal cycles follow LWP
  - Higher COD in P-case compared to C-case (20~30%)

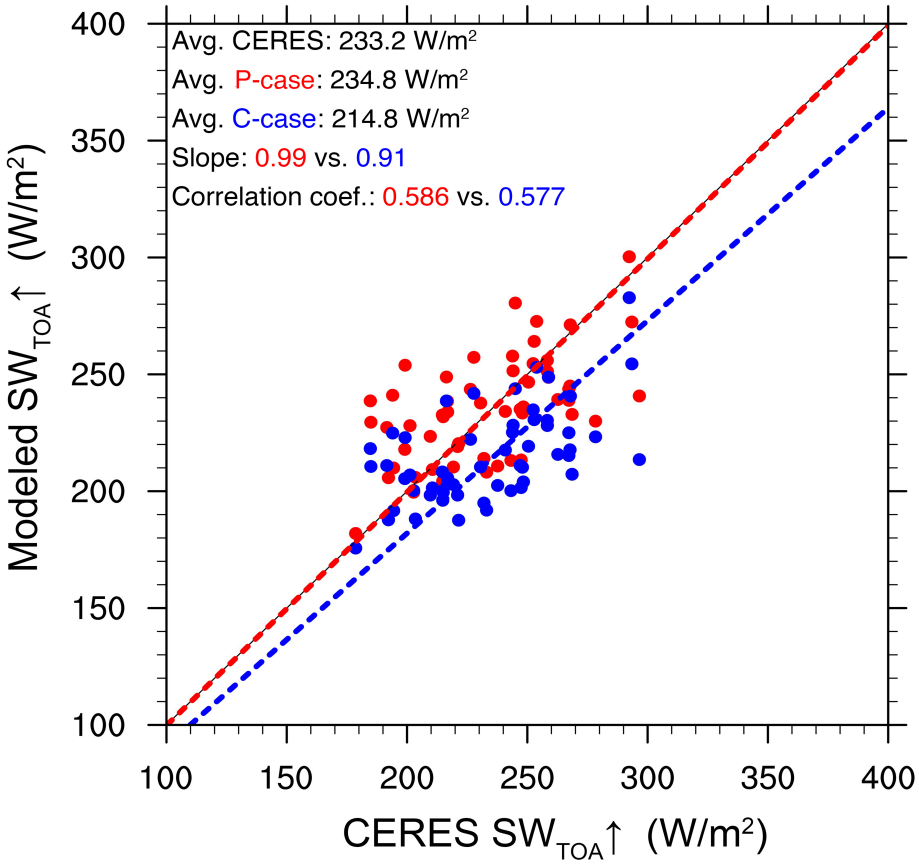
BB aerosol effects on cloud fraction





- **Total effect of BB aerosols (○)**
  - Enhances cloud fraction (CF) before noon, and reduces CF in afternoon (especially for the remote region)
- **Semi-direct effect (□)**
  - Enhance CF over the coast region in afternoon (consistent with the previous studies, e.g. Wilcox, 2012)

BB aerosol effects on radiation energy budget



	SEA domain	Coastal region	Remote region
Total effect	-8.05 (-20.0)	-6.88 (-18.0)	-8.93 (-21.6)
Microphysical effect	-7.01 (-18.6)	-8.28 (-21.7)	-6.12 (-16.5)
Direct + semi-direct effects	-1.04 (-1.4)	+1.40 (+3.7)	-2.81 (-5.1)

- Better agreement with CERES observations of SW_{TOA}↑ (daytime)
  - P-case: 1.6 W/m² higher
  - C-case: 18.4 W/m² lower
- The microphysical effect of BB aerosols causes strong cooling
  - Daily mean: **-7.01** W/m²
  - The cooling is mainly due to higher N_d (Twomey effect)

Conclusions

- In this study, we employ WRF-Chem model to study the impacts of BB aerosols on stratocumulus clouds over SEA during the fire season of 2014.
- Modeling results, in conjunction with satellite observations, suggest that BB aerosol microphysical effect (especially the Twomey effect) can cause strong cooling (-7.01 W/m^2) over this region.
- The findings in our study may partially explain the underestimation of cloud radiative forcing over this region predicted by GCMs.

PNAS

Biomass smoke from southern Africa can significantly enhance the brightness of stratocumulus over the southeastern Atlantic Ocean

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